BUILDING A GLOBAL NETWORK

SAFE AND SUSTAINABLE USE OF TETRACHLOROETHYLENE IN PROFESSIONAL TEXTILE CLEANING BY BEST PRACTICE APPROACH

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Safe and Sustainable use of Tetrachloroethylene in Professional Textile Cleaning by Best Practice Approach
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1. Summary

Tetrachloroethylene (PERC) is still a widely used solvent in the professional textile care industry. It is important for the industry to take scientific substantiated measures that guarantee the health and safety of people and environment. With the development of equipment, chemicals and work methods, safe and sustainable use of solvents in the professional textile care industry can be guaranteed. The current legislation in the European Union, and meanwhile beyond, limits the PERC emission and exposure to secure health and environmental safety. Regulation concerning emissions and exposure in the European Union is based on the Solvent Emission Directive (SED) 2010/75/EU (former VOC directive 1999/13/EC, which stated a total emission limit value of 20 g/kg cleaned garment. Technical developments and innovation in (machine) technology the last decades have reduced the emission levels even far below the values stated in the VOC directive. Because PERC is in use in the industry for a long time, extensive research and studies are available to the health and safety effects of exposure to PERC. Many of these studies are evaluated by health organisations like the WHO and EPA resulting in a scientific based, well evaluated conclusion on the relation between exposure and health effects of PERC. Extensive studies have been conducted with regard to the ailments of the central nervous system, liver and kidneys, procreation and the development of unborn children, and the risk of cancer. To define safe exposure limits for employees and surrounding residence conclusive evidence of health studies are used, taking uncertainty factors up to 400 into account. The recommended guideline for life long exposure by surrounding residence is 250 µg/m$^3$ annual average by the WHO. Based on this guidelines indoor and outdoor air quality regulations are set up by the Dutch government: 250 µg/m$^3$ on average per week indoor and 250 µg/m$^3$ on average per year outdoor for surrounding residence and areas. When exposed to these values it will not lead to direct danger for human health. Values for occupational exposure of dry cleaning employees (only during work hours) to PERC were set up to ensure a healthy and safe working environment. Although the conclusions of the studies are similar the regulations can differ per country due to different safety margins or interpretations. In The Netherlands a TWA value of 138.000 µg/m$^3$ is set by the government including a safety factor of 5. In the USA a value of 170.000 µg/m$^3$ is recommended by ACGIH and 690.000 µg/m$^3$ is set by OSHA as mandatory maximum level without the safety factor.

Evaluation of up to 215 dry cleaning companies in The Netherlands on the emission situation and the improvements needed to meet the regulations resulted in measures and working methods that can guarantee safe and sustainable processing. An 80%-reduction of emission was achieved after implementation of the best practice methods. With the present knowledge and use of the current available modern technology, chemicals and work methods emissions can be reduced to far below the limits, identified to cause potential danger for human health. To create awareness and exchange the knowledge the international educational program E-DryClean was developed to introduce best practice approach and to be able to guarantee a healthy, safe and sustainable professional textile care industry in Europe and beyond. Certification programs give incentives to the dry cleaners to improve operation and give the ability to communicate the safe and sustainable operation to customers and surrounding residence. Research concluded that professional textile cleaning, when it comes to environmental impact, scores on average two up till three times better than domestic textile cleaning with a dryer when best practice methods are used. The results prove: working according the best practice approach guarantees a healthy, safe and sustainable processing in professional textile cleaning.
2. Conclusions
Working according the best practice approach guarantees a healthy, safe and sustainable processing in professional textile cleaning. With the use of the current available modern technology, chemicals and working methods emissions can be reduced to far below the limits, identified to cause potential danger for human health. By creating awareness and knowledge, and applying the best practice working methods the professional textile cleaning industry can keep ahead of regulations by safe and sustainable processing.

3. Introduction
In the professional textile care industry tetrachloroethylene (PERC) is a widely used solvent. Despite the technological developments and improvements of the last decades, the discussion about safe and sustainable use of PERC is on-going. To prevent extreme measures it is important for the industry to take measures that guarantee the safety of people and environment. The current legislation in the European Union, and meanwhile beyond, often extended by the national governments, limits the PERC emission and exposure to secure health and environmental safety. Awareness, applying good practices and safe working methods will guarantee safe and sustainable working, regardless the use of the type of solvent. The scientific background of the best practice approach to achieve safe and sustainable processing in the professional textile cleaning industry will be explained in this report.

CINET, the International Committee of Textile Care, is the umbrella organization pooling national textile care associations. National associations, from all parts of the world, and associate members reinforce the organization through their professional expertise. These associate members are mainly research institutes and technical centres in Europe, Asia, America and Australia. Because of this worldwide network of organisations, concerned with the professional textile care industry, CINET is able to create international awareness, disseminate knowledge and unite the industry and governmental organisations to stimulate safe and sustainable processing in the global professional textile care actively. The best practices were laid down in E-DryClean, an E-Learning program from which education result in durable work methods in the professional textile care industry. This is the base of the “International Standard, Best Practices in Safe & Sustainable Professional Textile Cleaning” document, which describes the vision of the industry on durable and sustainable professional textile care.

TKT is the Dutch Technological Knowledge centre Textile care. TKT is closely affiliated to the Dutch associations Netex (Dry Cleaning) and FTN (laundry and textile rental), as well as the international umbrella association for the textile care industry, CINET. TKT initiates and coordinates technological projects for both the dry cleaning industry and laundry industry. The main purpose of these projects in general used to be to save costs, by the development of new and the optimization of existing technology to save water, energy, and labour costs. More and more TKT cooperates with end-users and suppliers in the textile care chain in projects to save energy, textile material, and water in the textile chain e.g. by expanding the life time of textile products. This is within a wider scope where TKT initiates and coordinates projects in which products and technology are developed to expand the added value of the textile care industry and to strengthen its market position. The safe and sustainable processing subject fits within the scope of the projects.
4. Use of Perc
Tetrachloroethylene or perchloroethylene (PERC) has been extensively used since the 1930s. PERC is important as a chemical intermediate and as solvent. The main application as solvent is dry-cleaning and metal de-greasing. PERC is a fully chlorinated C2-hydrocarbon of the formula C2Cl4. PERC is mainly used: [22]
- as starting raw material to produce fluorinated hydrocarbons and fluorinated polymers, other fluorinated derivatives like trifluoroacetic acid and trichloroethylene (through reduction).
- as solvent mainly for professional dry cleaning, in industrial textile treatment and for surface (mainly metal) cleaning.
- as reactant for catalyst regeneration in the petrol industry.

There has been a decline in production since the mid-1980s due to more efficient dry-cleaning processes, greater recycling, use of enclosed systems and other best practices. In the USA the overall (not only dry-cleaning) production of PERC has fallen from 350 Kton in 1981 to 169 Kton in the mid 1990's [25]. The overall European market of PERC reduced from 88 Kton in 1994 to 41 Kton in 2011, which includes the increased use of PERC in the metal degreasing as substitute for trichloroethylene [22, 24]. In dry cleaning, PERC is used as solvent that removes fats, greases, waxes, and oils from delicate natural or man-made fibers. However, because of the declining popularity of formal wear, improved efficiency of dry cleaning equipment, and increased chemical recycling, the demand for PERC as a dry cleaning solvent has declined over the last decades. In dry cleaning operations 60% - 90% of the shops in Europe use PERC, depending in the country. Due to legislation and available alternatives the amount of PERC used is decreasing.

5. VOC Regulations
Regulations concerning emissions and exposure in the European Union are based on the Solvent Emission Directive (SED) 2010/75/EU (former VOC directive 1999/13/EC), which applies for all countries in the European Union. As stated in the directive: “This Directive lays down rules on integrated prevention and control of pollution arising from industrial activities. It also lays down rules designed to prevent or, where that is not practicable, to reduce emissions into air, water and land and to prevent the generation of waste, in order to achieve a high level of protection of the environment taken as a whole”. Dry cleaning is defined in the SED as activity in Annex VII, with a total emission limit value of 20 g/kg cleaned garment Dry cleaners are responsible for an administration to prove that their solvent emission is below this limit. With the current dry cleaning equipment the administration of solvents added to the machine and the mass of the garment cleaned is sufficient to prove that the emission is below 20 g/kg garment.

The solvent emission directive is applicable to all Volatile Organic Compounds. According to the Directives definition any organic compound having at 20°C (293.15 K) a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use is a volatile organic compound. This means that the detective should be applied when the solvent used in dry cleaning operation 1) is an organic compound and 2) is volatile under the particular conditions of use. According the European classification almost all solvents are organic, except CO2 and water.
6. Equipment

Tetrachloroethylene or PERC is one of the oldest and most used dry cleaning solvent used nowadays. From the 1950s PERC cleaning was operated in transfer machines. The cleaning of the garment and the drying was separated and the wet garment has to be transferred form the cleaning equipment into the drying equipment. Sometimes this type of equipment is referred to as the 1st generation PERC equipment. Due to the transferring of the wet garment 300-500 g PERC per kg cleaned garment was used. The next or 2nd generation combined the cleaning process with the drying process in one machine. This reduced the use of PERC significant to 100-150 g/kg. To reduce the use of PERC during the cleaning and drying cycle even further new equipment was developed with dry-to-dry refrigerated cooling to remove the solvent during drying. Also carbon filters are installed for post cleaning of the vented air. This equipment can be referred to as the 3rd generation equipment. The solvent use is reduced to 40-80 g/kg cleaned garment. In the 1980s the 4th generation equipment is introduced. This equipment no longer vented air into the surrounding and was equipped with a chilled cooling reducing, the temperature to -20°C, lowering the concentration PERC in the cleaned garment. The result was equipment with a solvent use of 20-40 g/kg cleaned garment. The equipment is introduced in 1990s and is equipped with activated carbon integrated in drying loop to efficiently reduce the residual concentration of PERC. This equipment, referred to as 5th generation, has a typical PERC consumption lower than 10 g/kg cleaned garment. The latest commercial available equipment is a completely closed system with regeneration of activated carbon filters to reduce the amount of PERC used even further. The residue can be treated inside the machine to minimize the amount of PERC and an emission free unloading system is available. The industry reports a typical consumption of 3 g/kg garment for new equipment [23]. New equipment to enable secure safe and sustainable operation even further is currently under development.

![Figure 1: Average solvent consumption in g/kg cleaned garment (TKT)](image-url)
The technical innovations limiting the solvent emission range from closed drying loop and deep cooling, to condensation of the evaporated PERC, towards integrated activated carbon and emission free unloading systems in the state of the art equipment. In many countries regulations demand the use of dry cleaning equipment not older than 15 years. This means that the equipment used by the dry cleaning industry is from the 5th or even the state of the art 6th generation, limiting the emission of solvent significantly by using state of the art technology. The best practice method also recommends use of equipment from the 4th generation or higher. Also procurement criteria’s tend to limit the solvent emission. As an example the Dutch government requires in the procurement criteria’s “criteria for the sustainable procurement of Workwear Cleaning Services” that the equipment used should be from the 6th generation [14].

The technical developments and innovations combined with local regulations on the age of used machines guarantee a limited emission of PERC from the dry cleaning equipment. The main emission source, the dry cleaning equipment, is hereby significantly improved over the last decades, preventing the emission of large amounts of PERC during normal operation. The use of state of the art equipment enhances safe and sustainable processing in the dry cleaning industry.

7. Health and safety effects PERC exposure

Because PERC is in use in the industry for a long time, extensive research and studies are available to the health and safety effects of exposure to PERC. Important concepts are the so called NOAEL and/or LOAEL. The NOAEL (No Observed Adverse Effect Level) is the highest possible concentration in which no damaging effects are presumed. The LOAEL (Lowest Observed Adverse Effect Level) is the lowest possible concentration in which damaging effects are presumed.

Effects of exposure to very high concentrations, on the short term, can cause the following symptoms: irritation of the eyes, dizziness, sleepiness, light headedness, lessened locomotion and coordination. These short term effects have been determined with the use of experimental subjects [6].

Long term effects and possible carcinogenicity of course cannot be researched with experimental subjects; but these follow from epidemiologic research and possibly from animal tests.

Epidemiologic research takes place as follows. Extensive research is conducted to the health of a certain population, of which it is suspected that it has been exposed to a certain substance for a longer period of their life. This concerns mostly a certain occupational group which has worked with this substance, and then mainly the employees which have performed these tasks for decades. The degree in which certain illnesses and ailments can be detected in this group are compared to the average population. If it can be determined that a certain ailment is statistically significant more often present in this group, it is presumed that this ailment is the consequence of exposure to this substance. It is thus important in epidemiologic research that the test group is large enough. It is obvious that these are expensive studies which also take a lot of time.

When certain ailments are presented above average, a qualitative relation is drawn between exposure to a certain substance and presence of a certain ailment. However, this does not determine a quantitative relationship.
The question of which degree of concentration of a substance is damaging is still very difficult to answer. An estimate is made of the exposure, possibly in combination with measurements of where the specific substance is used. Often, the concentrations measured in working spaces are determined as concentrations in which negative health effects will certainly occur. This calculation can contain a large diversity of factors, so that a very clear quantitative relation cannot always be reached.

Epidemiologic research has been conducted with regard to the ailments of the central nervous system, liver and kidneys, procreation and the development of unborn children, and the risk of cancer. The results of these studies have been described extensively in [7] and [20] and are critically regarded in [6].

There are two epidemiological studies in which proof can be found for negative health consequences as a consequence of long term (occupational) exposure to PERC concentrations, which can be found in surroundings where work with PERC is carried out. One study concerns a study with regard to possible development of kidney damage as a result of long term exposure to PERC. The PERC concentration in which these effects could occur is analyzed and determined to be 102.000 µg/m$^3$ (range trace 102.000 – 576.000 µg/m$^3$) [7]. It should be mentioned that the Health Council does not confirm the results of this study [6]. Another study has established a clear reduction in response time with employees who for 10 years have been exposed to an average of 103.000 µg/m$^3$ [7]. The Health Council states, also with regard to this study, that the conclusions can not sufficiently be supported [6]. For ailments with regard to the liver, procreation, development of unborn children and cancer, no evidence is found in the epidemiological studies.

Finally, animal testing can be used to see if exposure to (highly) increased concentrations of the substance will lead to comparable ailments for animals. Laboratory animals can be used for multiple purposes, however test results valid for animals are not always automatically valid for humans. From animal tests with mice, an increase in the number of cases of liver cancer has been determined with concentrations from 680.000 µg/m$^3$ and an exposure of 6 hours per day, 5 days a week. With this concentration, mice also show deviations in the kidney cells. These values lead to a LOAEL of 680.000 µg/m$^3$, which have been mentioned as a base in several regulations. It needs to be mentioned that animal tests using rats show that clearly higher concentrations of PERC are necessary to determine the same results with rats [7]. The EPA review in 2012 stated that the characterization “likely to be carcinogenic to Humans” by all routes of exposure is based on suggestive evidence of carcinogenicity in studies and conclusive evidence that the administration of tetrachloroethylene, either by ingestion or by inhalation to sexually mature rats and mice, increase tumor incidence [20]. The EPA concluded in 2012 that the potential human health hazard for development and reproduction is based on a range of data from appropriate well-conducted studies in several laboratory animal species, but limited human (epidemiological) data are available [20].
8. Guideline definition

Many of these studies are evaluated by health organisations like the World Health Organisation (WHO) and U.S. Environmental Protection Agency (EPA) resulting in a scientific based, well evaluated conclusion on the relation between exposure and health effects of PERC.

The WHO guidelines for indoor air quality: selected pollutants (2010) describes: “guidelines for the protection of public health from risks due to a number of chemicals commonly present in indoor air, amongst which Perc. The guidelines are targeted at public health professionals involved in preventing health risks of environmental exposures, as well as specialists and authorities involved in the design and use of buildings, indoor materials and products. They provide a scientific basis for legally enforceable standards”. The guidelines of the World Health Organization stated the following main evidence [7]. “Carcinogenicity is not selected as the endpoint for setting the guideline value for three reasons: the epidemiological evidence is equivocal, the animal tumours detected are not considered relevant to humans, and there are no indications that PERC is genotoxic”.

The effect evidence, on which the guidelines are based, is: Effects in the kidney indicative of early renal disease and impaired neurobehavioral performance. Possible kidney damage is observed in a long term exposure study on dry cleaners, resulting in a LOAEL (lowest observed adverse effect level) of 102.000 µg/m³. Another study has established a clear reduction in response time with employees who for 10 years have been exposed to an average of 103.000 µg/m³. The WHO states: “The evidence of an association between PERC exposure and effects on the liver is suggestive”. Also other studies to reproductive and developmental effects have limitations. Therefore the evidence is suggestive and not taken into account for guidelines [7]. Meaning that 102.000 µg/m³ is the lowest possible concentration where an observed adverse health effect is presumed.

Based on the value of 102.000 µg/m³ a guideline value has been calculated. The value from this study is based on a working week of 40 hours. The LOAEL value is therefore recalculated to continuous exposure by a factor 4.2 (168/40). Due to uncertainties in the LOAEL, because of fluctuations in the exposure level, and variation between humans an uncertainty factor of 100 (10 for use of a LOAEL and 10 for intra-species variation) is applied. The recommended guideline for life long exposure is 250 µg/m³ annual average by the WHO. A short term guideline is considered not appropriate by the WHO due to acute effects that only occur at very high concentrations compared to generally observed levels in close proximity to dry cleaning facilities. “Establishing a long-term value is more protective of human health” according the WHO.

As a result of the Eleventh Circuit Court of Appeals decision (AFL-CIO versus OSHA), OSHA’s permissible exposure level for tetrachloroethylene, which was lowered to 170.000 µg/m³ (25 ppm) in 1989, was returned to 690.000 µg/m³ (100 ppm) in 1993. The TLV of 690.000 µg/m³ (100 ppm), based on human exposure data, contains no safety factor for individuals more susceptible to the subjective and neurological symptoms of tetrachloroethylene. The mandatory value by OSHA is therefore 690.000 µg/m³ in the USA. Based on human data, the ACGIH recommends a TLV-TWA value of 170.000 µg/m³ (25 ppm) [21]. The position taken by EPA’s Science Advisory Board in 1987 regarding the carcinogenicity classification for tetrachloroethylene, which was reiterated in 1991, has not changed since 1987.
This assessment is based on “increased liver tumors in male and female mice, kidney tumors in male rats, and, possibly, mononuclear cell leukemia in male and female rats”. The Science Advisory Board concluded that tetrachloroethylene “is an example of a chemical for which there is no compelling evidence of human cancer risk, but for which reductions in unnecessary human exposure might well be prudent.” [21]

9. Regulations

Several organizations have drawn up (inter)national regulations with regard to the PERC concentrations in the indoor and outdoor air based on scientific studies. As an example in The Netherlands the indoor and outdoor air quality surrounding textile care companies is regulated by the Activity Ordinance (Activiteitenbesluit)[5] and is based on the prevention of PERC related health effects for people surrounding textile care companies. The Dutch Health Council has postulated limiting values for the exposure to PERC in the working place which are controlled by the RIVM.

Air Quality

The regulations for air quality are based on the guidelines of the WHO study, the Activity Ordinance (Activiteitenbesluit)[5] determines that the maximum value of indoor air exposure (for neighbours) is on average 250 µg/m$^3$ (0,035 ppm) per week. The maximum outdoor air concentration of PERC surrounding sensitive objects is on average 250 µg/m$^3$ (0,035 ppm) per year. When people are not exposed a whole week (for example only during working hours) the values can be adapted to the exposure time. When setting up the guideline on which this regulation is based, it has explicitly been mentioned by the World Health Organization that carcinogenicity is not selected as the end-point for setting the guideline value for PERC. From this can be concluded that when following regulations, exposure to PERC will not lead to direct danger for human health.

Figure 2: locations and values for tetrachloroethylene [10]
TWA value – 8 hours
The TWA value for occupational exposure to PERC, which the Dutch Health Council applies, is 138,000 µg/m³ (20 ppm). The TWA value is based on average exposure on the basis of an 8h/day, 40h/week work schedule. The Health Council has based this value on studies with experimental subjects which have been exposed to different concentrations of PERC for short period of time. The review is based on neurotoxic effects like headaches, sleepiness, speech disorders, locomotion and coordination. It was determined that several effects occurred at values of 690,000 µg/m³ [6]. A safety margin of factor 5 presents the mentioned TWA value. On the dry cleaning shop floor the RIVM applies 1050 µg/m³ (0,15 ppm) as value for employees and customers [10]. This TWA value will ensure no neurotoxic or other health effects when employees are exposed to PERC. For neighbours an even lower value is applied by the Dutch RIVM guaranteeing no health effects for surrounding residence. In the USA the Occupational Safety and Health Administration (OSHA) has set mandatory permissible exposure limits (PELs) of 690,000 µg/m³ [11]. The American Conference of Governmental Industrial Hygienists (ACGIH) has a voluntary Threshold Limit Value (TLV) of 170,000 µg/m³ [11]. NIOSH recommends that tetrachloroethylene be handled as a chemical that might potentially cause cancer and states that levels of the chemical in workplace air should be as low as possible.

TWA-STEIL value – 15 minutes
The Health Council advises that, when exposed for a very short period of time, the NOAEL for the influence of the nervous system is 750,000 µg/m³. To correct this for individual differences between people, a factor 3 is applied. This presents a TWA-STEIL value of 250,000 µg/m³ (35 ppm) for a maximum of 15 minutes [9]. The TWA-15 minutes or TWA-STEIL is based on spot exposure for a duration of 15 minutes, that cannot be repeated more than 4 times per day. The TWA values are regulated on national level in every country, therefore the values can differ between countries. The values are often based on the same studies and results but differently interpreted.

<table>
<thead>
<tr>
<th>Tetrachloroethylene</th>
<th>TWA - 8 hours</th>
<th>TWA-STEIL - 15 min</th>
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<tr>
<td></td>
<td>ppm</td>
<td>mg/m³</td>
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<tr>
<td>United Kingdom</td>
<td>50</td>
<td>345</td>
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<td>The Netherlands</td>
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<tr>
<td>Australia</td>
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</table>

Figure 3: Overview national TWA values for PERC
[source: SER; OSHA; ACGIH; NIOSH; Safe work Australia, WORKPLACE EXPOSURE STANDARDS FOR AIRBORNE CONTAMINANTS,2011]
The regulations and values are based on extensive studies and evaluations by health organisations resulting in a scientific based, well evaluated conclusion on limits and the relation between exposure and health effects of PERC. The regulations and values are evaluated regularly. New studies changing the conclusions significantly are not available, although other interpretation of the numbers and safety margins can change the limits as well. An extensive knowledge base on the health effects of PERC is available. This knowledge should be used to create a safe and sustainable workplace and environment when working with PERC. Awareness, equipment and working methods should guarantee limited emission so exposure of PERC will not lead to direct danger for human health when these maximum values are not exceeded.

10. Development of best practice approach in The Netherlands

In The Netherlands several projects were executed from 2000 to 2004 to investigate the situation on emission and the improvements needed to meet changing legislation. Measures and methods are developed to meet the new legal requirements on safe and sustainable processing. In 2000 the government performed a “quick scan” to investigate the situation by measuring the indoor air quality in buildings surrounding dry cleaners [2]. As a result the project “cleaner production” was started by the Dutch association for dry cleaners, evaluating up to 215 companies in The Netherlands creating awareness and introducing safe and sustainable working methods [1]. This project resulted in insight in emission values and best practice work methods and methodologies to reduce them. In close cooperation with the Dutch government in 2004 a certificate was developed by the project “cleaner production for the development of an environmental certificate”. The certificate stimulated the dry cleaners to incorporate the best practice work methods and created awareness amongst them. The certificate guarantees the health and safety and creates a communication tool to show customers and surrounding residence that the dry cleaner produces safe and environmentally friendly [3]. The knowledge gained on working methods and best practices during these projects are disseminated to the international dry cleaning industry by setting up an E-Learning program, which is currently distributed across the world by CINET.

Reduction of emission

Based on the previous mentioned projects several actions to reduce emission were identified and described in best practice work methods. In general the options of the best practice approach consist of good housekeeping, optimal equipment and good working or operational methods. In a majority of the companies emission of solvents were caused by the equipment itself. Leakage or emission when unloading the cleaned garment appeared to be the most important source of solvent emission. Some options to prevent or reduce the emission is proper maintenance and the use of state of the art equipment from > 4th generation. Also optimising the drying procedure could reduce the emission in more than 70% of the companies. When emission occurred, which not necessarily exceeded the limit, it should be removed by ventilation in a way which does not influence the surrounding areas. In this way the PERC emission will stay at a safe concentration. To prevent diffusion of PERC to surrounding building or to the soil the construction of the building should have a gas barrier and spill containers (or an impermeable floor) should be used. The inventorisation of the improvement options by the project “cleaner production” is displayed in figure 4.
The effect on surrounding indoor air quality
During the project awareness was created and advices were given to the dry cleaners to reduce their emission. At the start of the project the air quality in the surrounding buildings was measured. The results corresponded with the results from the project “quick Scan” by the Dutch government a year earlier. After the advices a random test was executed to measure the effect of the project on the air quality. The effect of the optimisation is clearly visualised in figure 5. The figure shows the measured concentration of PERC in the indoor air in buildings surrounding the companies before and just after the project “cleaner production” in 2002. The amount of companies meeting the emission value for neighbours, 250 µg/m³ (0.035 ppm) average concentration per week, is doubled to 63%. More important the companies exceeding the 1500 µg/m³ per week are reduced to zero. In the project “quick scan” the RIVM stated that below 1500 µg/m³ (6 times the maximum limit) the health effects from several months till one year exposure can be neglected [2]. The total average emission level was even reduced with 80% from an average emission of 1831 µg/m³ to an average emission of 331 µg/m³ per week by implementing the advice and working according the best practice work methods.
So, creating awareness, identification of possible measures to prevent emission and communication of the best practices resulted in an 80% decrease in emission in about a year. These results from 2002 are promising and prove that by implementing best practice approach safe and sustainable processing in the dry cleaning industry can be guaranteed.

**Improvement air quality after certification**

In close cooperation with the Dutch government in 2004 a certificate was developed with the project “Cleaner production for the development of an environmental certificate” to guarantee the health and safety and create a communication tool to show customers and surrounding residence that the dry cleaner produces safe and environmental friendly. In this project 193 companies participated from which 52% did receive a certificate, guaranteeing safe and sustainable production in line with the legislation and regulations. The emission in the other companies was often just above the limits. They did receive an advice on how to optimise equipment, production or work methods to meet the requirements for the certificate.

To obtain a certificate the values in the companies should be in line with the emission values used by the RIVM. As previous mentioned, the main options to limit emission are the equipment and the drying process. Comparing the values of the companies, receiving the certificate as result of the 2004 project, with the values of 2001 the improvement becomes clear. In figure 6 we see an slight improvement of the emission above the equipment, but in figure 7 a significant improvement is measured above the unloaded garment. This is caused by optimisation of the drying process, but also improvement in machine technology contributes to the reduction of emission.

![TWA values above equipment](image1)

**Figure 6:** Percentage of companies below or above TWA value of 138.000 µg/m³ (20 ppm) measured above the equipment [1].

![TWA values above clothing](image2)

**Figure 7:** Percentage of companies below or above TWA value of 250.000 µg/m³ (35 ppm) measured above the cleaned clothing directly after unloading [1].

11% of the companies receiving the certificate improved the equipment by maintenance, regular checks and repairing leakages as showed in figure 6. In figure 4 is shown that in 90% of the companies optimisation of the equipment is possible, although in only a small amount of the companies (11%) it leads to exceeding the TWA 8 hour limits. The TWA short term values above the unloaded garment on the other hand were exceeded by 77% of the companies before certification. Optimisation of the drying process is the most important measure to limit the emission as showed in figure 7. Awareness of optimal drying conditions combined with the right load volume can significantly contribute to limiting the emission of solvent.
Also new developments in equipment will reduce this source of PERC emission. These results clearly prove that advice and education on optimal processing and stimulating improvement by certification can significantly reduce emission of PERC. The awareness created by the professional textile care industry about health, safety and environment in relation to the daily business caused a major improvement. Therefore these results were the reason to develop the international educational program E-DryClean to introduce best practice approach and be able to guarantee a healthy, safe and sustainable professional textile care industry.

11. Working methodologies
To implement safe and sustainability effectively in the dry cleaning industry and help the dry cleaners to optimise the dry cleaning operation and minimise emission, best practice working methodologies are set up. Several associations, governments, health, safety and environmental institutes have published best practice information [11, 12, 13].

What is best practice approach? Even a theoretically perfect process will not function if in practice rules are not accurately followed, (environmental) damage can occur as result. Therefore it is of great importance that awareness is created and knowledge on equipment and working methods is transferred.

Based on the previous mentioned projects several actions to reduce emission were identified and described in best practice work methods [1]. The most important measures taken to reduce emission are:

1. Optimisation of the drying procedure
When the drying procedure is not optimally adapted to the (amount of) garments cleaned increased solvent emission is possible when unloading the garments. In 59% of the companies evaluated an elevated level was measured. After optimisation of the extraction time and/or drying time, optimisation of the deep cooling installation, cleaning of the installation and/or optimisation of the load, all companies reduced the emission during unloading to values below the limits.

2. Detect and repair leakages of the equipment
The majority of leakages are caused by simple maintenance issues like leaking seals. Cleaning and replacing of the seals solved the leakage in the majority of the cases. Currently a regular check on leakages of the equipment and registration of the checks is mandatory. A spill container should be installed below the equipment or a liquid-tight floor is required to prevent contamination from leakages.

3. Improve the barrier between the dry cleaning shop and adjacent buildings
Because the limits in neighbouring buildings are significant lower compared to the TWA values for dry cleaning shops, emission of PERC towards neighbouring buildings should be prevented. Therefore proper gastight barriers should be installed, especially in the ceiling and floors. During inspection often holes for electrical wires or central heating systems were noticed. These should be properly sealed as well. When the measures are implemented the concentration of PERC in neighbouring buildings decreases significantly.
4. Improve the placement of ventilation exhaust pipes and equipment ventilation
When limited emissions occur a proper ventilation systems should be in place to prevent a build-up of concentration in the (indoor) working environment. The regulations on the ventilation systems in The Netherland describe the placement of exhaust pipes to make sure the surrounding buildings and areas are not affected and the concentration of PERC is quickly diluted to safe concentrations.

5. Improvement of wastewater treatment (of solvent equipment), by steam, air or activated coal. It is recommended to treat the contact water before draining or to discharge the water to the certified waste haulers. Contact water contains traces of PERC dissolved in the water. Often national legislation requires maximum concentrations or applies restrictions to the disposal of contact water, e.g. in the Netherlands the maximum concentration PERC in waste water is 0.1 mg/litre (Article 4.102 Activiteitenbesluit). To meet the requirements of a maximum solvent concentration in waste water, treatment of contact water with air, steam of activated carbon is obliged.

6. Improvement of solvent / chemical storage, by spill containers and vented cabins
Chemicals should be stored safe. In many dry cleaning shops the solvent ordered is immediately added to the equipment. Nevertheless cleaning enhancers and spotting agents are chemicals as well. Therefore proper indication (flammable, irritating, etc.) and storage is necessary. Spill containers will prevent contamination and ventilation should be present as well.

7. Improvement of distillation residue storage, by spill containers and vented cabins
For the distillation residue the same rules are in place as for the chemical storage. When residue is stored outside the building it should be not accessible for others. The use of a closed unloading system is recommended

When looking at best practices in general to limit emissions the following rules can be applied.

- **Equipment:** Source reduction by using > 4th generation equipment, maintenance, leak detection, etc.
- **Operation:** Optimal machine operation like drying times, use of chemicals, cleaning enhancers, loading, etc.
- **Good housekeeping:** Containment by preventing spills to air, water and soil by using spill tray’s, closed containers, proper storage, proper maintenance/cleaning, etc.
- **Recycling:** Recovery and recycling by distillation, treatment of contact water, active carbon adsorption, waste/residue management, etc.

When the best practices work methodologies are applied according to the rules, safe and sustainable operation can be guaranteed complying with regulations and limits. Exposure to the working or surrounding environment will be limited and not lead to direct danger for human health or environment.
12. E-DryClean

One of the most extensive programs on safe and sustainable processing in the professional textile care industry is the E-DryClean program by Cinet [16]. This is an educational E-Learning program for the dry cleaning industry targeting the European employees in the professional textile care industry. The program describes the international and national legislation, solvent management, solvent technology, equipment technology, work methods and other aspects to limit emission and ensure a safe and sustainable working process. The goal is to create awareness for safe and sustainable processing and to train the employees in the best practice approach to guarantee a healthy and safe industry. E-DryClean is the results of a European Leonardo da Vinci project (NL/08/LLP-LdV/TOI/123016) to create practical and easily accessible education material especially for the European Dry-Cleaning industry. By doing so E-DryClean has set an international standard for best practices in sustainable processing in professional textile care companies.

E-DryClean brings out level 1 certificates based on the training on specific solvents and a level 2 certificate based on the total program. Students will be granted with the prestigious international E-DryClean certificate when they successfully finish their examination.

The E-DryClean project is implemented amongst European and even non-European countries. E-DryClean is now available in English, German, French, Dutch, Italian, Czech and Greek. Contracts are signed to deliver translations and learning material in Turkish and Russian. Also for China material is in development. E-DryClean is therefore not only a European program but it is used worldwide.

The best practices as described in E-DryClean result in durable working methods in the professional textile care industry and is the basis of the “International Standard, Best Practices in Safe & Sustainable Professional Textile Cleaning” document, which describes the vision of the industry on durable and sustainable professional textile care [17]. The document is worldwide recognised by prominent experts in the field.

13. Environmental impact

To determine the environmental impact of state of the art dry cleaning operation according to the best practices, Dutch research institutes TNO and TKT executed a study, commissioned by CINET [18]. The environmental impact of domestic textile laundry has been compared with professional textile cleaning on ten different aspects. In the study, the following processes are compared:

- Domestic laundering and drying
- Professional cleaning and drying with PERC
- Professional cleaning and drying with HCS
- Professional cleaning and drying with Jet spray system HCS
- Professional cleaning and drying with Jet spray system Siloxane D5
- Professional cleaning and drying with Siloxane D5
- Professional cleaning and drying with Glycol ether
- Professional cleaning and drying with Acetal
- Professional cleaning and drying with Wet cleaning
The CINET study is taking into account:

- The environmental impact of used energy sources during cleaning and drying
- The impact of the production of the used products and materials
- The impact of the emissions during cleaning and drying (including waste water treatment)

What is excluded from the CINET study is the possible pre and after treatment of garment, the impact of the surrounding area on the process and the impact related to the production, maintenance and discharge of the equipment itself.

The analysis of the impact is based on the following environmental effects:

- Depletion of abiotic resources (ADP)
- Acidification (AP)
- Eutrophication (EP)
- Climate change (GWP)
- Ozone depletion potential (ODP)
- Human toxicity (HT)
- Aquatic ecotoxicity (FAETP)
- Marine ecotoxicity (MAETP)
- Terrestrial ecotoxicity (TETP)
- Photochemical oxidant formation (POCP)

For all processes a model process has been set up with parameters based on practice [18]. For domestic laundry the average use of a dryer is taken into account. To compare the impact of the several environmental effects, the effects are recalculated to shadow costs. Shadow costs are the costs necessary to undo environmental effects. This method makes the effects comparable to each other. The study used SimaPro software with the Ecoinvent 2.1 database as background data set and the CML 2 baseline 2000, shadow price v2.05.2 for calculating the shadow costs. In figure 7.1, the total environmental impact of the model processes are compared. The results are presented as the shadow costs per 4 kg laundry in Euro’s.
This figure clearly shows that the environmental impact of the professional cleaning processes is significantly lower than the environmental impact of the average domestic laundry process. Especially the use of the dryer has a negative influence on the average environmental impact of domestic laundry. In the domestic textile cleaning process, energy consumption and detergency consumption (production of detergents) count relatively heavy. Innovations have largely contributed to the relatively low environmental impact of the professional textile cleaning. Technological innovations of dry cleaning equipment reduced the emission of the solvents significant. Therefore the environmental impact of the professional textile cleaning is also reduced. Development of the professional textile cleaning services and wet cleaning technology resulted in very mild (with water and soap) cleaned laundry by professional textile cleaners. This cleaning method appears to have a relative low environmental impact and therefore contributes to the reduction the overall environmental impact. Moreover, there is a clear synergy between the two cleaning methods: heated cooling water of the solvent cleaning equipment can be reused as wash water in the professional wet cleaning. This results in an increased reduction of the environmental impact of professional textile cleaning.

The professional cleaners who want to minimize environmental impact even further should mainly focus on the following areas (in order of importance):
- The method of heating the distillation and drying air
- The control of the machine (no longer than necessary drying, cooling and distilling)
- The consumption of solvent per kilogram cleaned garment
- The garment load factor of the machine
- The efficiency of the steam generation
- The efficiency of the utilization of heat from cooling water

It can be concluded that professional textile cleaning, when it comes to environmental impact, scores on average two up till three times better than average domestic textile cleaning when best practice methods are applied [18]. Current innovations and developments resulted in a safe and sustainable professional textile cleaning industry.

14. Current situation
Sustainability as a basic value for dry cleaners is a basic demand from customers, as revealed by market research [19]. Also in public opinion sustainability a major topic. Therefore the use of state of the art equipment and technology, chemicals and working methods is of high importance for the textile cleaning industry to fulfil the requirements from the customers, employees, neighbours, governments and many others on safety and sustainability. The dry cleaning companies certified by the Dutch association for dry cleaning (Netex) are all working according to the best practice methods as defined in the E-DryClean program. The certificates are re-evaluated every three years by auditing the companies by inspection and measurements. The companies working according to these best practices can all guarantee safe and sustainable processing without any negative health effects for customers, neighbours or employees. The certificate is the proof of safe and sustainable processing in line with all regulations. Based on the technological innovations and developments the current technology is already a step ahead of the regulations. The average consumption of PERC of the 5th generation equipment is below 10 g/kg of cleaned garments and the consumption of the state of the art equipment is even lower. This is a result of the active responding industry on the PERC issues. The modern technology can guarantee a safe working environment.
The success of applying the best practices as described in the E-DryClean program is also confirmed by research. TNO concluded that professional textile cleaning with PERC has a 2 times less environmental impact compared to domestic laundry when the working methods according to E-DryClean are used [18]. This result shows that working according the best practice approach is not only safe but also environmentally friendly.

15. Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>PERC</td>
<td>Tetrachloroethylene or Perchloroethylene Dry Cleaning solvent</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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<tr>
<td>EPA</td>
<td>US Environmental Protection Agency</td>
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<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
</tr>
<tr>
<td>ACGIH</td>
<td>American Conference of Governmental Industrial Hygienists</td>
</tr>
<tr>
<td>NIOSH</td>
<td>the National Institute for Occupational Safety and Health</td>
</tr>
<tr>
<td>PEL</td>
<td>Permissible Exposure Limits</td>
</tr>
<tr>
<td>TLV</td>
<td>Threshold Limit Value</td>
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<tr>
<td>TWA</td>
<td>Time Weight Average (8 hours)</td>
</tr>
<tr>
<td>TWA-STEL</td>
<td>Time Weight Average – Short Term Exposure Limit (15 minutes)</td>
</tr>
<tr>
<td>LOAEL</td>
<td>Lower Observed Adverse Effect Level</td>
</tr>
<tr>
<td>NOAEL</td>
<td>No Observed Adverse Effect Level</td>
</tr>
<tr>
<td>TCL</td>
<td>Tolerable Concentration limit</td>
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16. Reference

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P.O. Box 10, NL - 4060 GA Ophemert
Phone: +31 344 65 04 30    Fax: +31 344 65 26 65

e-mail: cinet@cinet-online.net    www.cinet-online.net